PUMPING IN THE METROPOLITAN WATER DISTRICT OF MASSACHUSETTS[1]

By Alfred O. Doane

The Metropolitan Water District of Massachusetts was established by an act of legislature in 1895. It includes the city of Boston and seventeen other neighboring cities and towns, and had an estimated population in 1916 of 1,190,220. The average daily consumption of water in the District for 1916, of which half was supplied by gravity, was 103,876,000 gallons or 87.3 per capita.

The water supply is obtained from the old Boston reservoir No. 3 on the Sudbury River, the Sudbury Reservoir (commenced by the City of Boston and completed by the Metropolitan Water Board), and from the Wachusett Reservoir, constructed by the Board on the South Branch of the Nashua River at Clinton. Lake Cochituate, from which the first large supply for Boston was obtained, and the old Boston reservoirs on the Sudbury River, except reservoir No. 3, are now held in reserve.

Half of the water drawn from the Wachusett and Sudbury reservoirs is brought to a point in Weston, through the Weston Aqueduct. It then flows through 60-inch and 48-inch cast-iron pipes and furnishes the gravity supply to the lower parts of the District. Spot Pond, in the extreme northerly part of the District, is connected with this pipe system and acts as a storage and compensating reservoir. The remainder of the water drawn from these reservoirs, together with the water from the old Boston reservoir No. 3, is conveyed by the Sudbury Aqueduct to Chestnut Hill Reservoir. All this water is pumped at the Chestnut Hill Pumping Stations. When water from Lake Cochituate is used, it comes to Chestnut Hill Reservoir through the Cochituate Aqueduct.

On January 1, 1898, the City of Boston pumping stations came under the control of the Metropolitan Water Board, and the Mystic Pumping Station and several of the smaller stations in the District

[1] Read before the Richmond Convention, May 8, 1917.

were shut down. When the new Metropolitan pumping stations were completed, all of the small pumping plants were abandoned, and all the pumping for the District is now done at five stations by high-duty pumping engines instead of at seventeen widely separated stations by low-duty pumping machines of a type now obsolete.

All the water delivered to the Chestnut Hill Reservoir is pumped at two pumping stations located on the southeasterly side of the reservoir. The older building, known as Chestnut Hill Pumping Station No. 1, was built by the City of Boston in 1887.

Chestnut Hill Pumping Station No. 1. The pumping plant consists of two 8,000,000-gallon Gaskill horizontal flywheel engines, built by the Holly Manufacturing Company in 1887; one 20,000,000-gallon vertical triple-expansion crank-and-fly wheel engine, with Riedler mechanically operated valves in the water end, designed by the late E. D. Leavitt and built by the Quintard Iron Works in 1895; and one 30,000,000-gallon vertical triple-expansion crank-and-fly wheel engine, built by the E. P. Allis Company in 1898.

The boiler plant consists of one Belpaire boiler, 90 inches in diameter and 34 feet long; two vertical Dean boilers, 98 inches in diameter and 24 feet long; and three horizontal tubular boilers 64 inches in diameter and 18½ feet long. There is also a 168-tube Sturtevant economizer.

Only a comparatively small quantity of water is now pumped at this station, as most of the water for the supply of the higher portion of the southerly part of the District is pumped at Pumping Station No. 2 by the 40,000,000-gallon Holly pumping engine.

Chestnut Hill Pumping Station No. 2. This station was built by the Metropolitan Water Board in 1900. The pumping plant consists of four vertical triple-expansion crank-and-fly wheel engines, all built by the Holly Manufacturing Company; three of these engines are of 35,000,000-gallon capacity each and were installed in 1900, and the fourth is of 40,000,000-gallon capacity and was erected in 1911.

The boiler room contains five boilers, all of the vertical fire tube type, designed by F. W. Dean. The three older boilers are 98 inches in diameter, 29½ feet high over all, and each contains 384 2-inch tubes 15 feet long. The other two boilers are 109 inches in diameter and 29½ feet high over all, and each contains 484 2-inch tubes 15 feet long.

There are two 144-tube economizers, one a Sturtevant and the other a Green.

The coal house has a capacity of 1,000 tons, and the loaded cars come in to it on a trestle about 15 feet high. An ash tunnel extends under the boilers, and the ashes are dumped through an opening in the floor into a car in the tunnel. The loaded ash cars are raised to tracks outside the building leading to the dump, by means of a hydraulic elevator.

The 40,000,000-gallon engine is used for supplying the southern high-service district and operates against an average head of 124.54 feet. The three older engines pump water for the lower parts of the district, including the low lying portion of the city of Boston.

Owing to a large increase in the amount of water supplied by gravity, the pumping to this service has been much reduced and the pumps are now largely used to regulate the pressure in the mains by supplying water during periods of maximum draft and to raise the pressure during large fires.

The combined daily average high service pumping at both of the Chestnut Hill Pumping Stations was 34,371,300 gallons in 1916; the average lift was 124.13 feet; the cost per million gallons pumped, based on pumping station expenses, was $3.0682.

The low-service pumping was done at Station No. 2 and amounted to a daily average of 33,875,000 gallons from January 1 to February 7, 1916. On February 8 a large main supplying water by gravity from the Weston Aqueduct was put in service, and the daily average pumping for the remainder of the year was 15,365,000 gallons. The average lift was also reduced from 41.51 feet to 33.70 feet. The change, while reducing the total cost of water pumped about $4000 raised the cost of pumping per million gallons to $4.14, or $1.80 more than in 1915.

The Spot Pond Pumping Station is situated on the shore of Spot Pond. The engine room contains a Holly 20,000,000-gallon vertical triple-expansion crank-and-flywheel engine and a 10,000,000-gallon vertical compound crank-and-flywheel engine designed by the late E. D. Leavitt and built by the Blake Manufacturing Company. This engine was erected at the Mystic Pumping Station of the City of Boston and was transferred to Spot Pond in 1899, after the Mystic Station was abandoned.

The boiler room contains three Dean vertical internally fired fire tube boilers 92 inches in diameter, 29 feet 4 inches long over all, each containing 256 $2\frac{1}{4}$ inch tubes 15 feet long.

A Green 144-tube economizer is used to heat the boiler feed water.

The water is pumped from Spot Pond to the Fells and Bear Hill Reservoirs. From these reservoirs it is distributed to the higher portions of the northerly part of the District. The daily average quantity pumped in 1916 was 7,106,000 gallons, against an average lift of 129.06 feet. The cost of pumping was $5.8289 per million gallons.

The northern extra high service pumping station is located in Arlington and pumps water from the low service system for the supply of the higher parts of the town of Arlington and for the entire supply of the town of Lexington. The pumping plant consists of one Allis-Chalmers cross-compound crank-and-flywheel engine and one Blake compound duplex engine used as a reserve pump. Both have a daily capacity of 1,500,000 gallons.

There are two 54-inch horizontal tubular boilers in brick settings.

The daily average pumping in 1916 was 797,000 gallons; the average lift was 281.7 feet; and the cost per million gallons pumped was $36.42. This was partly due to extensive repairs to the Allis-Chalmers engine and more extended use of the low duty Blake pump.

The southern extra high service pumping station is located in the Hyde Park district of Boston, and pumps water from the southern high service mains for the supply of elevated territory in the southern part of the district.

The station contains two 3,000,000-gallon cross-compound crank and flywheel engines built by the Laidlaw-Dunn-Gordon Company, and two 54-inch horizontal tubular boilers in brick settings. The daily average pumping in 1916 was 655,000 gallons; and the cost per million gallons pumped was $30.31.

The five pumping stations are operated under the direction of the Superintendent of Pumping Stations, Arthur E. O'Neil, who reports to William E. Foss, Chief Engineer of Water Works. The men work in eight-hour shifts, and are allowed one day off in seven and a vacation with pay.

Coal and lubricating oil are purchased under specification and are regularly tested at a laboratory at the main office of the Board in Boston. In addition to the laboratory tests of fuel, special boiler tests are made from time to time, especially when changes in the brand of coal used are contemplated. In this way much information regarding the actual working of the coal is obtained, which is not shown by the calorimeter or other laboratory tests.

Synopsis of coal specifications. The coal shall be of good quality,

free from dirt and excessive dust, a sample of which when dried at 221°F., hereinafter called dry coal, will approximate the following standard of heat value and analysis:

British thermal units	14,800 per pound
Volatile matter	18 to 20 per cent
Ash	7 per cent
Sulphur	1 per cent

Coal which when dry contains less than 14,300 B.t.u. per pound, more than 23 per cent of volatile matter, more than 9 per cent of ash, or 1.50 per cent of sulphur may, at the option of the chief engineer, be rejected, and if rejected shall be removed by and at the expense of the contractor.

For each 50 B.t.u. or fraction thereof in the dry coal in excess of 14,800 the price per ton shall be increased 1 cent, and for each 50 B.t.u. or fraction thereof less than 14,700 the price per ton shall be decreased two cents.

For each $\frac{1}{2}$ of 1 per cent or fraction thereof of ash in the dry coal in excess of 8 per cent the price per ton shall be decreased one cent.

When the analysis of the coal shows moisture in the coal as received in excess of 3 per cent, the amount of weight due to moisture in excess of 3 per cent shall be deducted from the total weight of the coal, and the net weight so determined shall be taken as the amount of coal to be paid for.

Coal for the pumping stations has been purchased on the heat unit basis since 1908 the board having been one of the pioneers in adopting this method of buying coal. The specifications as outlined above have given general satisfaction and are fair to both dealer and consumer, which is an important point. Fuel suited to the type of boiler, as well as draft and load conditions, is obtained and any loss of efficiency due to a poor lot of coal is compensated by the reduction in price.

Limiting the volatile matter is of considerable importance where vertical internally fired fire tube boilers are in use, as it is difficult to obtain complete combustion of a high volatile coal before the gases strike the heating surfaces of the boiler.

The limitation of sulphur is desirable, as this element in combination with iron and other constituents of the ash is apt to form bad clinkers, and also from the fact that the presence of two per cent or more of sulphur is in most cases a very good indication that the coal

is liable to spontaneous combustion. While it is well known that this action is due to absorption of oxygen by the coal, both sulphur and moisture seem to play an important part in starting the trouble, although some coals low in sulphur heat badly while others high in sulphur do not.

Boiler-room management. As the greatest opportunity for economy is commonly found in the boiler room, particular attention is paid to this part of the plant. Care is taken to see that the method of firing and depth of coal on the grates is suited to the fuel and load, that the tubes and heating surfaces and other parts of the boiler are kept clean, and the boilers are washed out at regular intervals. Particular care is taken to keep the lower tube sheets of the vertical boilers free from scale to avoid overheating the tube ends. The brick settings of horizontal boilers require careful watching to avoid infiltration of air through cracks or porous masonry.

Recording steam gages have a considerable moral effect on the firemen, and in connection with log charts giving the hourly readings of instruments in the engine and fire rooms keep the superintendent informed of what goes on in the plant during the entire twenty-four hours.

An apparatus for the continous determination of CO_2 is installed at Pumping Station No. 2, but has not proved very satisfactory in operation as, owing to its delicate and complicated construction, it is liable to get out of order and requires more expert attention than it is practicable to give.

Leaks in steam pipe lines are promptly repaired, as it is astonishing how much loss may be caused by an apparently insignificant leak.

There are four fuel economizers in service, but the conditions are not favorable for large savings owing to the steady load and large proportion of heat absorbed by the boiler heating surface, with consequent low flue temperature. The economizers do, however, act as settling reservoirs and to a limited extent as feed water purifiers, and as steam driven auxiliaries are scare in the Metropolitan stations they add some heat to the feed water, which would otherwise have to be obtained from live steam in order to comply with the state law, which requires boiler feed water to have a temperature of at least 120°F.

Careful attention to methods of firing, such as depth of fire, regulation of draft, working of fire, charging and spreading of coal, makes

for economy. As a general rule, charging small amounts of coal frequently and maintaining as thin a fire bed as practicable give the best results. Hand firing is the method employed, although stokers have been used and also forced draft with hand firing. There is considerable danger in using forced draft in internally fired fire tube boilers of getting a blow pipe or Bunsen burner effect, causing intense local heating which results in burning the furnace sheets or crown sheets and tube ends.

It has been found economical to burn a certain proportion of small anthracite coal, known as birdseye, mixed with bituminous coal. From 25 to 50 per cent of birdseye can be burned with advantage with natural draft, depending on the draft available, load conditions and depth of fuel bed and characteristics of the coal used in regard to coking and clinkering. A larger proportion of birdseye can be used economically by carrying a thin fire bed, taking care to avoid the formation of holes and working the fire as little as possible. If the air supply is obstructed by a thick fuel bed or formation of clinkers, imperfect combustion ensues. If the fire is sliced or shaken too much, a large proportion of the fine coal falls into the ash pit unburned.

One advantage of using a considerable proportion of anthracite is that it greatly reduces the formation of smoke; another is that mixing it with a bituminous coal having an ash of low fusibility tends to prevent the formation of a layer of melted ash, which would cut off the air supply to the fuel bed.

The boiler feed water is metered and in most cases it is necessary to use a hot water meter. Various makes of these instruments of the disc, piston or rotary type have been tried, but all are unsatisfactory as they rapidly lose accuracy and require constant repairs. A Venturi meter gives the best results, as there are no moving parts in the hot water, but the great cost of the registers makes them out of the question for most small plants.

It has been found advantageous to use as small steam pipes as will allow of the proper admission of steam to the engine, and by the use of a large separator on the engine the size may be still further reduced. The advantages of a small pipe are low first cost of pipe, fittings and coverings, less radiating surface and consequent condensation, quicker passage of steam from boiler to engine, and greater flexibility of bends which reduces the strains due to expansion and contraction. The small size pipe is particularly advantageous when the steam is superheated.

While no large economies are possible in the engine room, care is taken to see that the valves of the engines are properly set, that cylinders and bearings are properly lubricated, that both steam and water packings are in good shape, and that the rubber pump valves are kept in good condition, otherwise there would be an excessive amount of slip. It is found that with outside-packed water plungers the slip should not exceed 1.5 per cent.

For packing single-acting water plungers, a packing made up in the form of a double wedge has been found satisfactory, as on the discharge stroke the water pressure forces the wedges together and prevents leakage, while on the suction stroke the packing is comparatively loose and causes but little friction.

For packing steam piston rods, metallic packing is used and it wears for years without attention.

Most of the air pumps and feed water pumps are direct connected to reciprocating parts of the main engines, and have the same length of stroke as the main plungers. This arrangement requires but little attention and has the same economy of operation as the main engine, but is not as flexible in operation as the independent steam driven pumps. The exhaust steam from the latter can be used to heat the feed water, giving a good over-all economy and saving the boilers from strains due to cold feed water.

The action of the long stroke pumps sets up violent strains in the piping unless it is well protected by air chambers kept filled with air.

Surface condensers are used exclusively. Some are of the so called water works type, where the exhaust steam passes through the tubes and all the water pumped passes through the shell, flowing over the outside of the tubes; while in others a portion of the water pumped is by-passed through the tubes and the steam is condensed on the outside of the tubes. As a rule, the water works type gives better satisfaction, as the circulating water is cooler owing to the larger volume, there is no trouble with by-pass devices, and the interior of the tubes is not clogged by any material carried by the water.

Efficiencies. The table on the next page gives the results of duty trials of some of the pumping engines.

The Arlington and Hyde Park engines are of the horizontal cross-compound crank-and-flywheel type; all others are vertical triple expansion crank and flywheel engines. The duties are based on plunger displacement, and where not otherwise noted on dry steam and coal.

LOCATION OF ENGINE	CAPACITY MILLION U. S. GALLONS IN 24 HOURS	AVERAGE LIFT	DUTY—MILLION FOOT POUNDS PER			EFFICIENCY	
			1000 Pounds Steam	Million B.T.U.	100 Pounds Coal	Mechanical	Thermal
		feet					
Chestnut Hill Pumping Station No. 1	20.0	137.48		145.470	150.045		
	30.0	140.35	178.497	157.002	173.869	93.29	21.63
Chestnut Hill Pumping Station No. 2	35.0*	44.68	157.349	140.533	156.322	88.23	20.50
	40.0	132.09	175.066	155.547	149.135	90.10	20.01
Spot Pond Pumping Station	20.0	125.27	173.620	156.592	177.961	96.53	20.85
Arlington Pumping Station	1.50	290.3	115.959†		90.025‡		
Hyde Park Pumping Station, Engine No. 14	3		121.022†	111.880	113.488‡	93.2	

* Average of three 35,000,000 gallon engines tested together.
† Moist steam.
‡ Moist coal.

In regular service the duties are computed weekly on the coal basis, and are therefore records of plant efficiency. It is found that where the conditions are such that the engines can run at rated capacity on 24-hour service, the results compare favorably with those obtained at duty trials, but where the engines are not run continuously or operate below the rated capacity, or, as frequently happens, are subjected to both these handicaps, the duty is seriously affected and may be only from 50 to 75 per cent of the trial duty, depending on conditions. The engines at the small pumping stations and the low-service pumping engines are particularly subject to these unfavorable conditions.

The efficiency of the boiler plants is satisfactory. All the large boilers are of the internally fired fire tube type, and as the load is steady while the engines are running and the boilers have ample heating surface for the work, very little heat goes to waste.

Carefully conducted boiler tests have shown that the Belpaire boiler has a combined efficiency of boiler, furnace and grate of 80.3 per cent and the Dean vertical boilers of 80.4 per cent. The horizontal tubular type boilers have shown an efficiency of 74 per cent under not particularly favorable circumstances.

In regular service the 109-inch Dean boilers gave for the year 1916 an average evaporation from and at 212°F. of 12.3 pounds of water

per pound of coal. The horizontal tubular boilers show from 9.5 to 10 pounds evaporation. These figures have proved stumbling blocks to parties who have proposed to install their fuel saving devices and have guaranteed a 25 per cent saving of coal.

The human element as represented by the pumping station force, particularly of the fire room division, is of the greatest importance. Unceasing vigilance on the part of the supervising authority, careful selection of the help and firm but considerate treatment of the men are necessary to get the best results. Many large corporations have adopted the policy of paying a bonus to the firemen, based on actual savings effected. This has in many cases effected a notable reduction in the fuel bill. This method, however, seems to be impracticable in state or municipal work.

In conclusion, a word of caution may not be out of place. While economy is desirable, it is well to remember that in the pumping service reliability is of paramount importance, and it does not seem good policy to endanger it by attempting to make small savings in machinery, supplies or labor.

DISCUSSION

Carleton E. Davis: Does the author buy oil on a specification covering flash point, viscosity and other similar factors? While specifications of this nature may be an aid, the speaker does not believe they are conclusive evidence as to the quality of the oil or its suitability for a particular purpose. As a matter of fact, he believes most specifications are arrived at synthetically; that is, certain trade oils furnished by particular concerns are tried out under actual conditions. If they give good results, the oils are analyzed to determine their quality. Future purchases may be made under a specification embodying the results of the analysis, but the speaker does not find that any guarantee can be made that an oil meeting the specification will produce results equal to those given by the original satisfactory oil. He has come to the conclusion that the most satisfactory way is to buy oil from a reputable dealer, who will examine the conditions and guarantee that his oil will produce satisfaction under those conditions.

Charles R. Henderson: A small operator does not have the organization to sample and analyze coal and oil and to do many of

the things mentioned in the paper. However, a great deal of benefit can be derived from the study of the paper by small operators, especially as to the keeping of records. While many of the records kept in large cities, perhaps, cannot be kept in a small plant, still it has been the speaker's experience that the keeping of more records will pay a very large return. The installation of recording instruments is a good thing even though much attention may not be paid to them. Sometimes the very fact that the instruments are there and records are kept has a great deal of influence in a beneficial way upon the operation of the plant. While the engineer of a small pumping plant may be discouraged when reading such papers as this, applying more particularly to large plants, thinking what a contrast there is between the operation of his plant and the larger ones, still he can get a great deal of benefit from such good contributions to our proceedings.

R. B. Howell: It is true that when pickups are bought the firemen are at a loss at times to know why they do not get uniform results in their work. However, all of the coal used by the Omaha water department is now analyzed, and the department has a list of all the coals that come into its territory and are likely to be offered. As a consequence, as soon as a man offers a consignment of coal, it is known at once about what its thermal value is, and purchase is made upon the basis of this knowledge. Therefore buying is not purely guess-work. The department has adopted a coal as a standard which comes from the Cherokee district in Kansas. These mines afford the best slack that comes into Omaha. Knowing the market value of this coal, it is easy to determine by referring to the list of relative values, whether the offer of any other coal is advantageous.

The department has also made practical tests of all of the coal reaching Omaha, so that its knowledge is not confined merely to its thermal value, but also covers its actual value in pumping station use. The department has arrived at that point now where it feels justified, when anyone says he has a certain amount of coal on the track and wishes to know what the department will give for it, in making a bid without hesitation.

J. N. Chester: The ability of the author to buy coal on specification certainly argues that the coal market is not overworked in his district as it is in western Pennsylvania, for there nothing can

be bought on specifications. Purchasers simply have to take what producers will give, and on any attempt by the purchaser to dictate the kind the producer merely advises the applicant to go somewhere else to get what he wishes as the producer can dispose of all his product in the regular way, whether it is coal or machinery.

The speaker has had the same experience as Mr. Howell in buying pickups at St. Louis and Jefferson City, Mo., and while saving is occasionally made by pickups it is better to buy on specification and obtain what is desired.

Mr. Henderson struck the right chord in what he said regarding the value of keeping records and about the operators of small plants obtaining valuable information by studying the methods in large stations, even though the methods cannot always be duplicated in small plants. But it reminds the speaker of his younger days when he stood gazing into a window of a confectionery shop with only a penny in his pocket and wished that he could buy all the good things displayed with his modest capital.

Alfred O. Doane: It is very true than an oil specification does not throw much light on the lubricating value of the oil. It is also true, as Mr. Davis said, that the label or selling agent has a great effect on the engineer. The author has known good oil to be condemned by engineers as inferior simply because it was not the kind that they had been accustomed to use. The author does not claim that oil specifications are a cure for all oil troubles, but his experience has been that some sort of specification is better than nothing. As a matter of fact, a specification is built up synthetically, as Mr. Davis says, to a certain extent from experimentation and ascertaining what grade of oil, what viscosity, and what general characteristics of an oil give the best results. It seems to the author that it is considerably better to build up a specification in that way than to have no standard at all. The Metropolitan Water Board has had the same experience as Mr. Day, that there is a remarkable difference in the price for the same oil depending upon whether it is bought by brand or by specification. The author is inclined to think that while oil specifications may not be ideal they at least give some good results.

The oil specifications of the Metropolitan Water Board are as follows:

Engine oil. Engine oil shall be made of high grade mineral oil, derived from a crude oil having a paraffine base, without admixture of animal or vegetable oils, and shall possess satisfactory lubricating and wearing qualities.

The oil shall be translucent, showing a medium red color by transmitted light, and shall be free from acid, lumps, tar and residue insoluble in gasoline.

The oil shall contain no oil thickener, soap, gelatine or similar substance added to artificially increase the viscosity, and shall be carefully strained into clean barrels.

The oil shall have a specific gravity at 60°F. between 28° and 31° Baumé, a flashing point not below 410°F., and a burning point not below 475°F.

At a temperature of 70°F. the oil shall show a viscosity between 185 and 205 seconds on the Tagliabue viscosimeter, and shall flow freely at a temperature of 20°F.

Dark cylinder oil. Cylinder oil shall be made from a high grade dark cylinder oil stock, derived from a crude oil having a paraffine base, possessing satisfactory lubricating and wearing qualities.

This stock shall be compounded with 5 per cent, by weight, of tallow containing as little free acid as possible, in such manner as to give a perfectly homogeneous mixture free from acid, lumps, tar and residue insoluble in gasoline.

The oil shall contain no oil thickener, soap, gelatine or similar substance added to artificially increase the viscosity and shall be carefully strained into clean barrels.

The oil shall have a specific gravity at 60°F. between 24° and 26° Baumé, a flashing point not below 525°F. and a burning point not below 600°F.

At a temperature of 212°F. the oil shall show a viscosity between 140 and 160 seconds on the Tagliabue viscosimeter, and shall flow freely at a temperature of 60°F.

It may be said that these specifications as to viscosity, besides being a measure of that particular property of the oil which is desired, have a very practical effect on the pumping station force. Formerly it was customary to obtain different lots of oil showing quite a range of viscosity, and considerable trouble was experienced in changing from one lot of oil to another. Now that trouble is eliminated. When bids for furnishing oil are requested, the specifications furnish a standard for competitors by which to know definitely what is desired and they can all bid on the same basis. Specifications will also aid very materially in securing a uniform product, which is a matter of considerable importance.